Overture
Sidereus Nuncius – Starry Messenger – G. Galileo

"About ten months ago a report reached my ears that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect several experiences were related, to which some persons gave credence while others denied them. A few days later the report was confirmed to me in a letter from a noble Frenchman at Paris, Jacques Badovere, which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterwards, my basis being the theory of refraction. First I prepared a tube of lead, at the ends of which I fitted two glass lenses, both plane on one side while on the other side one was spherically convex and the other concave. Then placing my eye near the concave lens I perceived objects satisfactorily large and near, …"

Animation due to Galileo and Tarwin Baker, a graduate student of Prof. Domenico Meli in the Department of History and Philosophy of Science at Indiana University. For even better one see

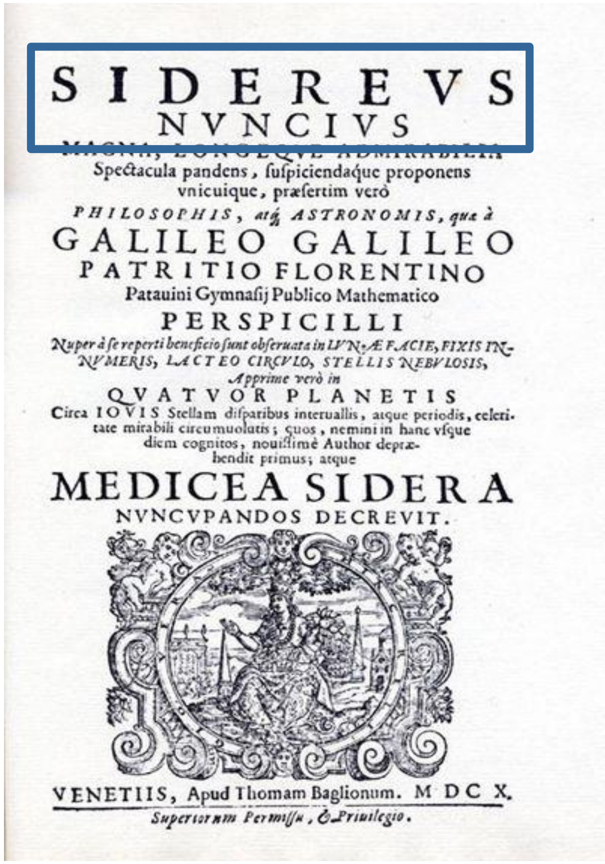
http://strangepaths.com/observation-of-jupiter-moons-march-1613/2007/04/22/en/

from Massimo Mogi Vicentini.

C:\Documents and Settings\carrigan\Desktop\Sidereus Nuncius slow-1.mov

Starry Messages: Searching for Interstellar Archaeology Signatures

Dick Carrigan –Fermilab – arXiv:1001.5455


SIDEREVS
NVNCIVS
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS INNVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissimè Author depræhendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

~1610
Starry Messenger
moons of Jupiter
Exoplanets of 400 years ago

Result – Galileo placed under house arrest for life

Galileo

Giordano Bruno – an infinity of worlds

1584: De l'Infinito Universo et Mondi
(*On the Infinite Universe and Worlds*, 1584)

1591: applied unsuccessfully for chair of mathematics in Padua, instead went to Galileo Galilei in 1592

Giordan Bruno

1601 burned at stake in Campo de' Fiori

What Fermilab seminars would Galileo and Bruno be attending now?

Solar system 400 years after Galileo

"The Mission of the Mars Exploration Rovers" John Grant

Discovery of exoplanets

"First Results from the Kepler Mission" Jason Steffen

Modern molecular-based biology

extremophiles, origin of life?

"Singularities in the Origin and Evolution of Life" C. de Duve

Particle cosmology, dark matter, dark energy,

cosmic landscape, anthropic conjecture

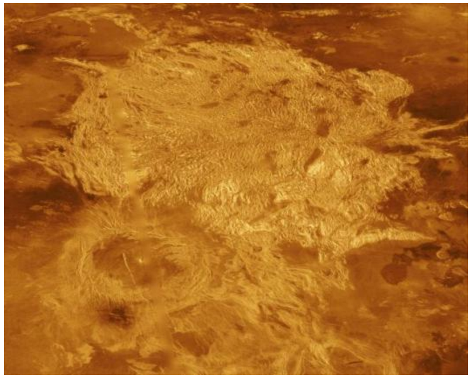
"Probing the String Landscape: Implications,
Applications, and Controversies" – Keith Dienes

…and SETI?

"The Allen Telescope Array: 42 is More than the Answer
to 'Life, the Universe, and Everything" J. Tarter

EXPLORATION OF THE SOLAR SYSTEM

Carl Sagan



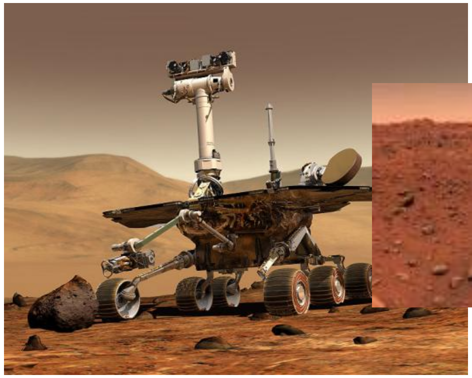
Venus: T= 735 K

p = 93,000 mbar CO_2

Earth: T= 300 K

p = 1000 mb

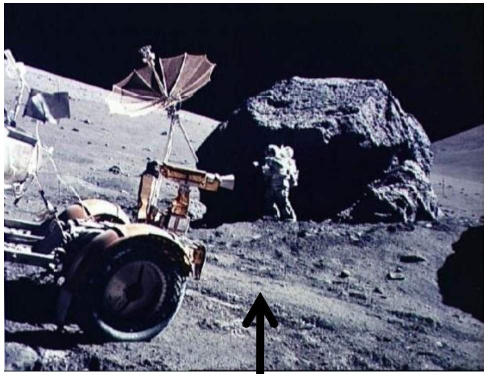
habitable



Mars: T= 190-270 K

p = 8 mbar CO_2-

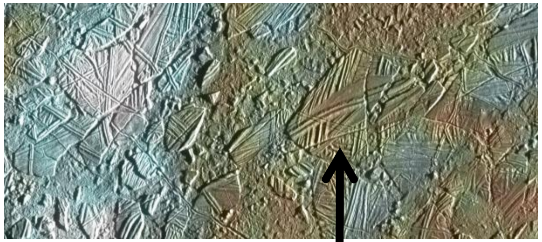
robotic



Moon: T= 100-390 K

p = 0, Schmitt (App 17)

capsule



Europa: T= 100 K

p = 10^{-9} mbar

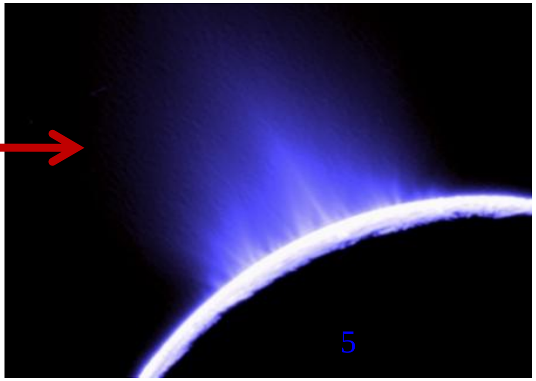
Extremophile?

Enceladus: T= 273 K

@geyser, mean 75 K

p = trace , H_2O

Extremophile?

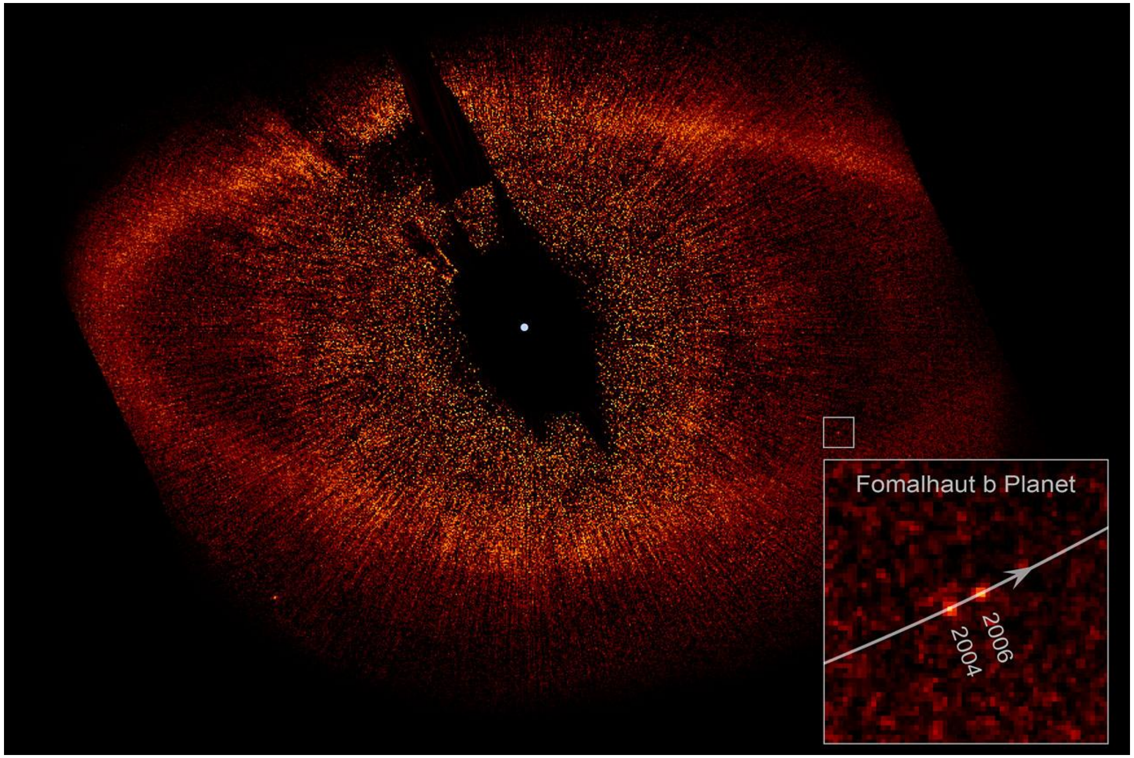


Exoplanets – 2010 to 2110

Exoplanet Community Report,
P. R. Lawson, W. A. Traub and S. C. Unwin, eds.,
JPL Publication 09-X, 2008 – draft,

"*It is ironic that what is arguably the most compelling subject in astronomy—the **search for other worlds** and other life beyond our Solar System—emerges only now, in the 21st century... We are indeed fortunate to live in the time when this last barrier to our search is coming down. It is reasonable to think that the **search for other worlds** and other life, even though limited for the foreseeable future to our own corner of the Milky Way galaxy, **will dominate astronomical research before mid-century.***"

Now have more than 400 exoplanets



Even direct image via Formalhaut b – Hubble

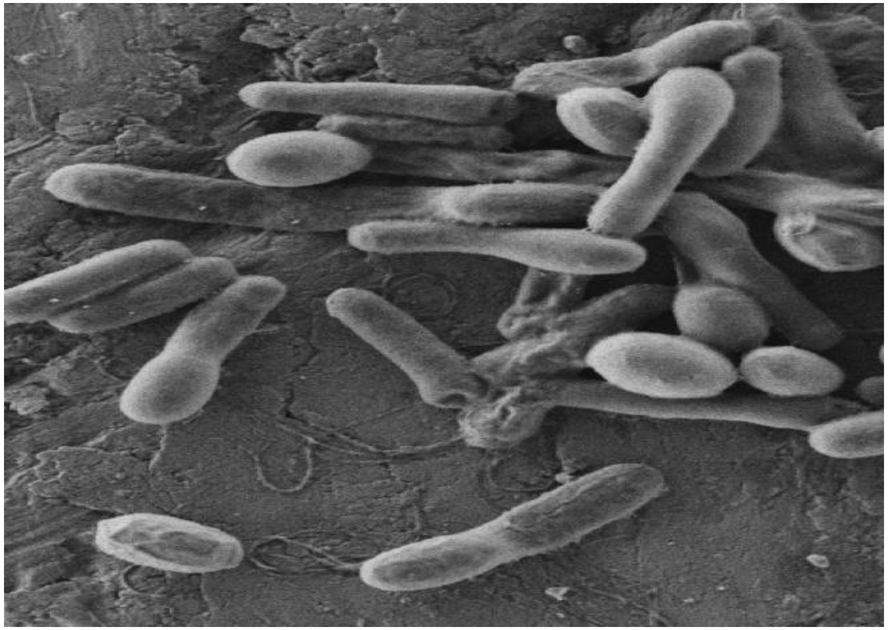
(Kallas)

(also 3 planets from HR 8799)

Advances in biology

Astrobiology as a field

Extremophiles



DUSEL

Extremophiles

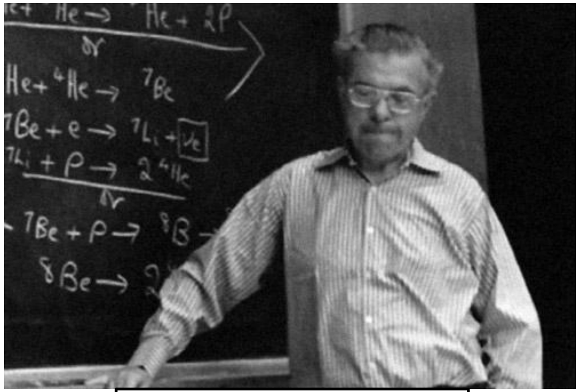
Bruce Bleakley, SDSU, et al.

Cellulose-degrading thermophiles isolated from SUSEL

DUSEL 2C-13 – GeobacillustibetanG6)

Origin of life – no significant sign on moon, Mars, but Europa, Titan and Enceladus?

Particle cosmology and the big bang, dark matter and energy, landscape, anthropic conjecture



Fred Hoyle

Landscape

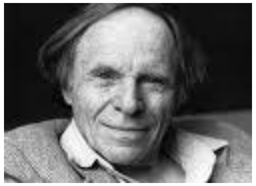
10^{500} universes or 10^{420} ways to assemble 10^{80} particles

Anthropic conjecture

a Universe just right for us (Carter)

Hoyle – triple alpha process

SETI and the RADIO SETI PARADIGM



Morrison

SETI radio beacon (acquisition signal) –but why?

Cocconi

Material and electromagnetic ET artifacts containing information don't require reason to communicate

A substantial fraction of sun-like stars out to several hundred light years have been monitored for ETI with radio SETI.

Credit: Allen Telescope

Organization of the talk

Interstellar archaeology
SETI – Drake equation
Kardashev scale
Examples of interstellar archaeology
- Exoplanet atmospheres
- Stellar salting
- Dyson sphere
- Stellar engineering
- Galactic scale – Annis
- Transgalactic scale

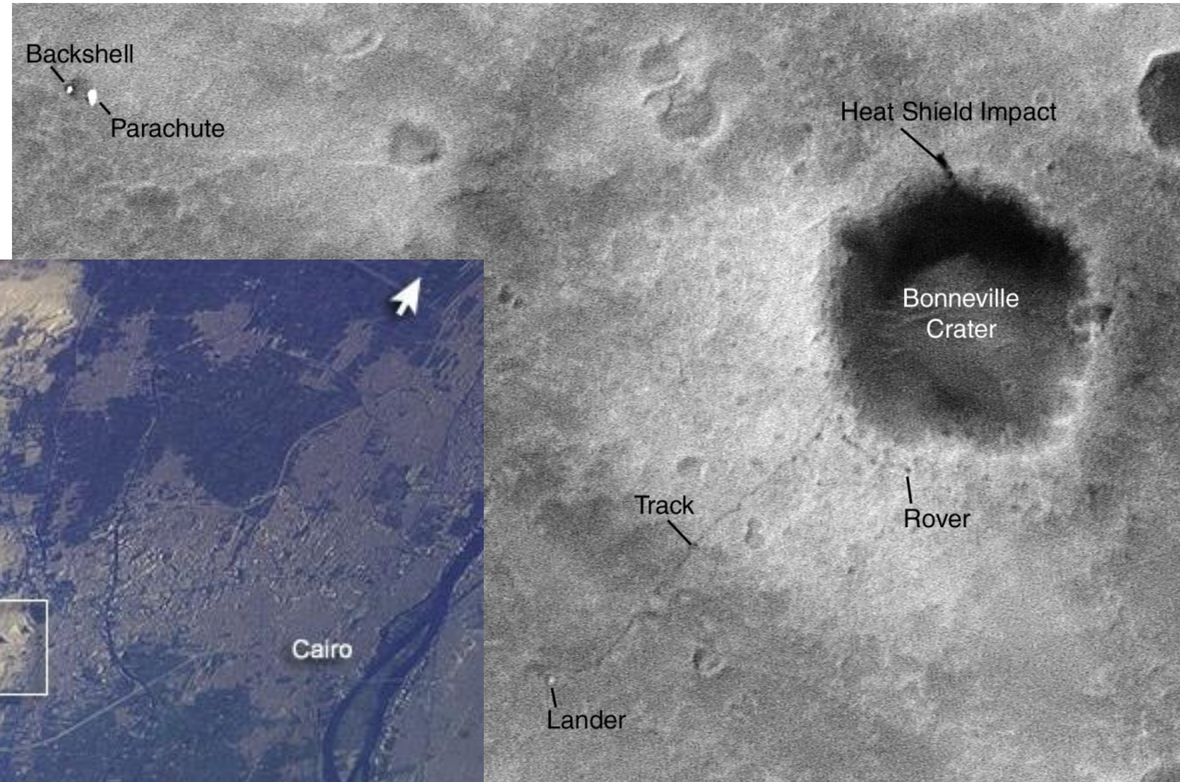
The interstellar archaeology landscape

Guillermo Lemarchand

General ref: Guillermo Lemarchand, SETIQuest, Volume 1, Number 1, p. 3.
On the web at http://www.coseti.org/lemarch1.htm

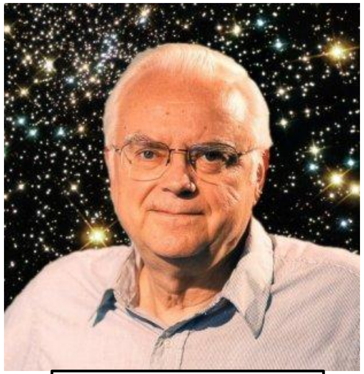
Examples of planetary or extraterrestrial archaeology

pyramids from space station



Mars Rover but maybe robot anthropology

SETI – the Drake equation



Frank Drake

$$N = R f_p n_e f_l f_i f_c L_c$$

R - formation rate of intelligent life-friendly stars

f_p - fraction of these stars with planets

N_e-average number of planets in a planetary system that are hospitable to life

f_l - fraction of these planets where life emerges

f_i - fraction of these planets on which intelligent life arises

f_c - fraction of these where an interstellar-worthy civilization emerges

L_c - length of time the civilization remains detectable.

For some archaeological process with effective life L_x

$$\boxed{N_x = f \frac{L_x}{L_c}}$$

where $$f = R f_p n_e f_l f_i f_c$$

Larger L_x helps!

SETI continued

Tarter: strong TV transmission out to one light year

Arecibo planetary radar out to 3000 ly.

An advanced civilization may emit less stray radiation

SETI may detect **cultural** as distinguished from intentional signals.

Jill Tarter

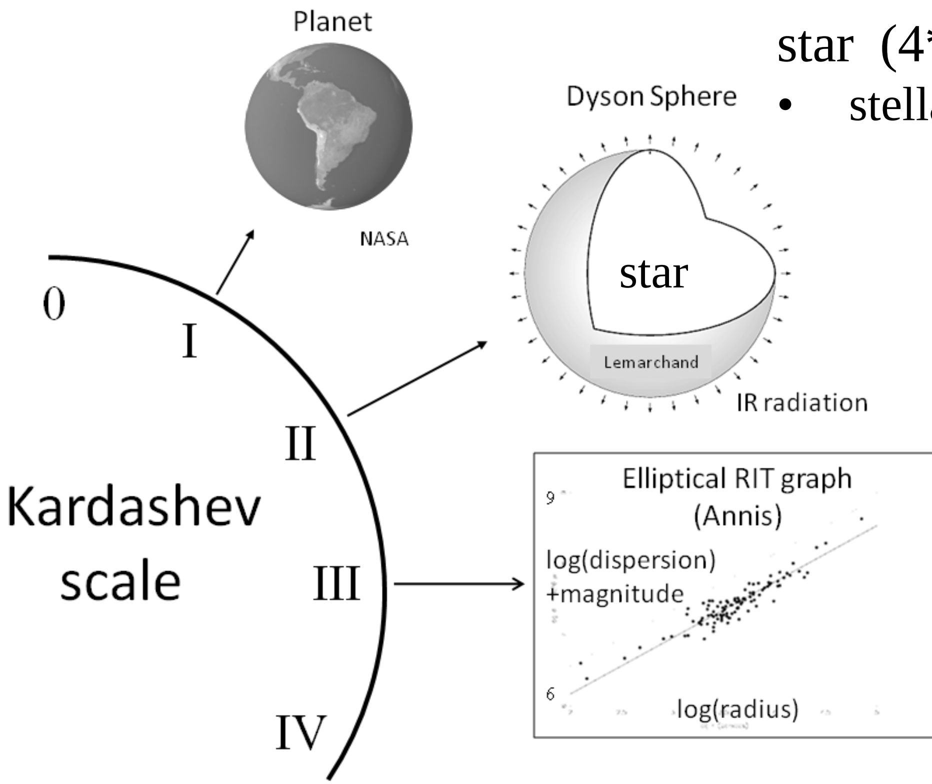
Kardashev scale

SETI

planet (10^{16} W)
- exosolar planetary atmospheres.

star ($4*10^{26}$ W Sun)
- stellar engineering

Nikolai Kardashev



galaxy (10^{36} W)

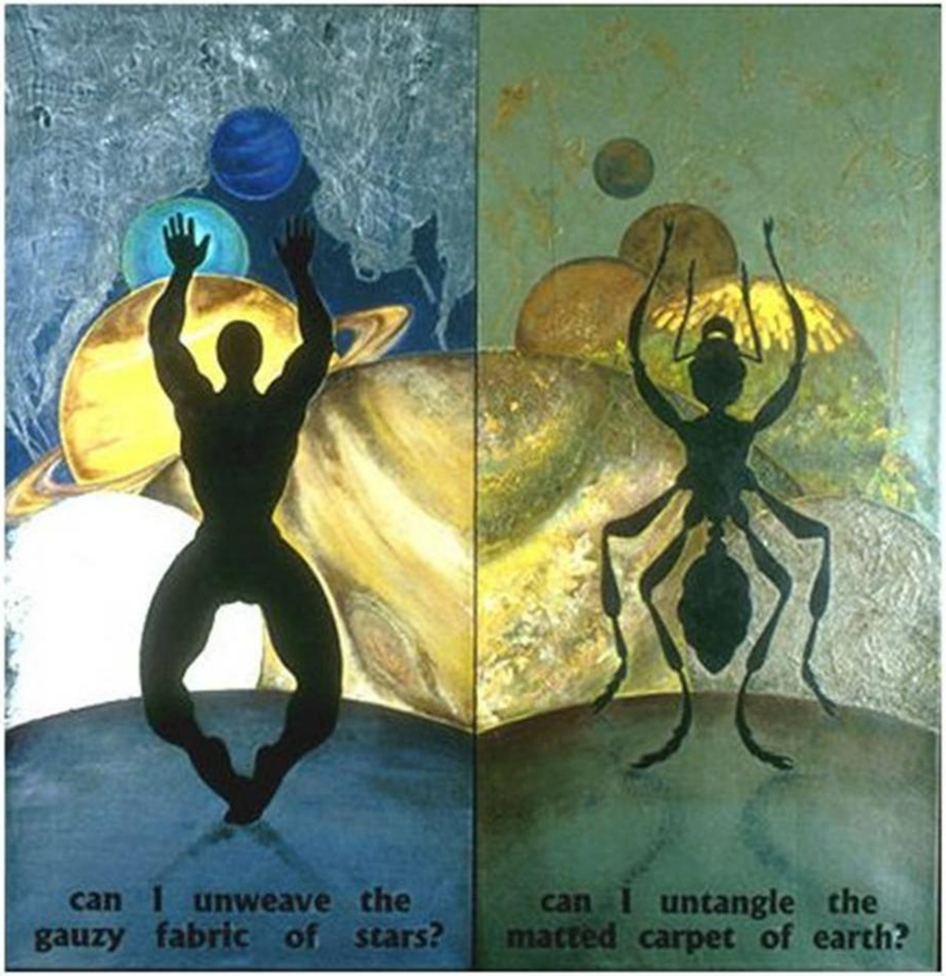
Extensions to the Kardashev scale

- Type IV might harness the energy from the visible Universe, defined by the comoving distance to the edge, on the order of 10^{13} large galaxies.
- This could be extended even further to Type V, to include the concept of multiverses (later slide).
- By the same token one could ask about smaller civilizations, for example a town of 10,000 people (Type 0; 100 W/person),
- several thousand fleas

(Type -I; 10^{-4}W),

- or mycoplasma genitalium (Type -II; 10^{-14} W). An individual mycoplasma genitalium contains on the order of a billion protons.

Covers much of the 10^{80} in Dirac's estimate of particles in the Universe



Astronomer and the Ant   Acrylic on Linen   Nancy Jean Carrigan © 2000

Signs of intelligence in exoplanet atmospheres

Extrasolar planetary atmospheres

first want life signatures (red edge, oxygen - Lovelock 1975)

in earth atmosphere CO_2 up by 35% in industrial times

For interstellar archaeology want **unique cultural signal – freons (chlorofluorocarbons or CFCs)?**

"CFCs are a very interesting idea to look for advanced civilizations," per Lisa Kaltenegger . …need exceptionally sensitive telescope. It might be feasible "in the far future with a flotilla of infrared telescopes in space".

Lisa Kaltenegger

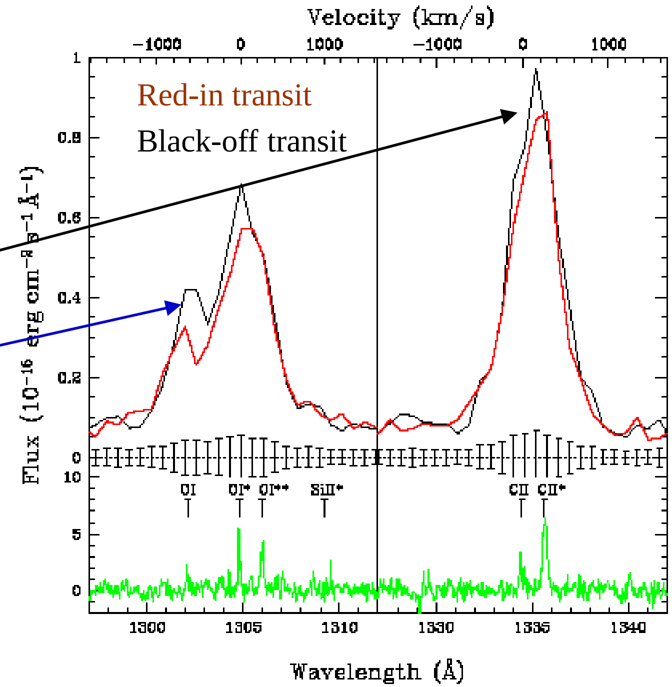
Progress on exoplanet atmospheres HD 209458 b or "Osiris" (150 ly)

STIS on Hubble for HD209458

- See spectral lines absorbed
  - by atmosphere
- HI
- CII
- OI

Also Charbonneau et al.

- Na atmosphere on Osiris



Spitzer also saw silicon – the stuff of computer life – SiO_2 clouds

Even more progress - HD 189733b (63 ly)

Now even methane, H_2O, CO, and carbon dioxide (Swain, et. al., HD 189733b, ApJ **690**, L114, 2009)

Giovanna Tinetti

too hot for even the hardest life … unlikely that cows could survive here!"

Also high altitude haze, energy redistribution (wind)

in the last week or so Swain et al., Nature 463, 617-618 (4 February 2010) have reported fluorescence from methane using a 3 m NASA Infrared Telescope Facility at Mauna Kea

but far from freon or CO_2 change

Degree of Difficulty

L_a ~ atmospheric perturbation
P_a ?
M_a ~ 10^{15} kg (δ mankind CO_2)

Stellar spectra - radioactivity salting

Drake and Shklovskii: artificially introducing a short-lived nuclear species with strong resonant absorption line into a star might signal the presence of an advanced civilization.

Technetium – no stable isotope – hour to million yrs

need order of 100,000 tons of technetium (world: 100 tons/7 decades)

(a big number, 10 kg – atomic bomb, 18 ton solar panel Shuttle)

Seen in red giants - variable S–stars – 3 DUP

(relates to neutron flux environment)

Need big telescope for spectroscopy - ESO VLT

Uttenthaler , et al., Mem del Soc Astron Ital, v.77, 961 (2006)

Find at galactic bulge (~30,000 ly)

L_{sp} ~ isotope lifetime

M_{sp} ~ 10^8 kg

Problem – natural signals

Stellar spectra - disposal of nuclear wastes

disposing of radioactive nuclear wastes?

if so their lines would be a possible indicator of intelligent civilization.

Looking for such signals is the cosmic equivalent of searching ancient waste dumps.

Whitmire & Wright, Icarus, 42, 149 (1980): artificially introducing a short-lived slow neutron product like neodymium or praseodymium with a strong resonant optical absorption line.

Plutonium– need nearly all of planet's fissile output.

$L_w \sim \lambda$ waste

$M_w \sim 10^8$ kg (scale of waste)

Problem – natural signals

Stellar spectra - modulation of stellar maser

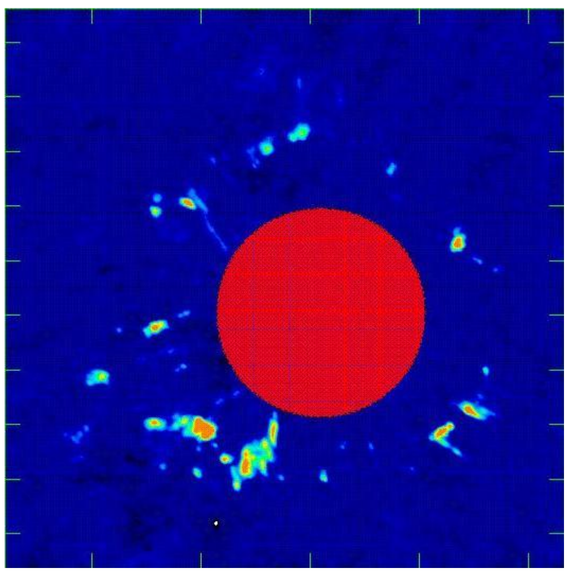
Might do by dust clouds (in stellar environment)

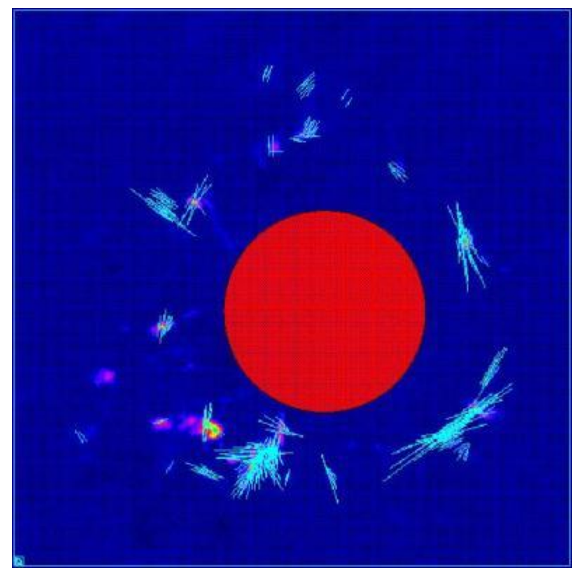
Or magnetic field modification

Mira variable TX Cam –movie of SiO maser dust clouds

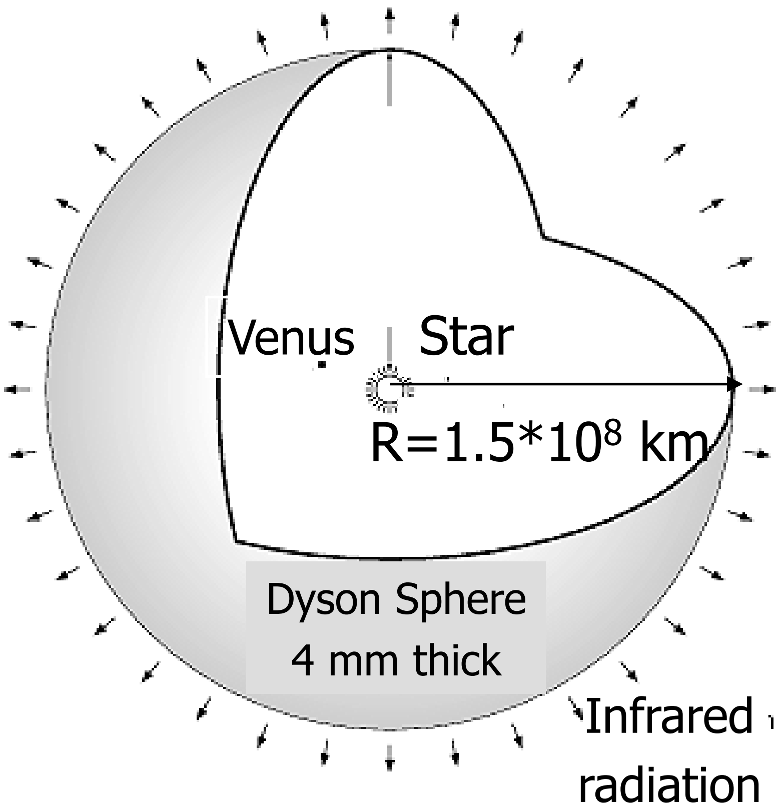
Diamond & Kemball, ApJ **599**, 1372 (2003)

Problem – faces in the clouds





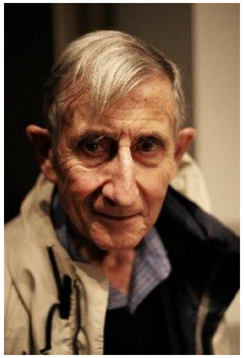
Dyson sphere



Lemarchand, http://www.coseti.org/lemarch1.htm.

Rationale

harvest all star's visible energy



Freeman Dyson

Types

pure – star completely obscured

partial

Signature

infrared

stellar luminosity (distance problem)

Planck-like

no star for pure DS

Energy to assemble - **BIG**

800 solar years to take Jupiter apart

Rigid Dyson sphere is unstable

instead cloud or shroud of smaller stuff

Dyson, Science, 131, 1667 (1960), Dyson & Carrigan, Scholarpedia, 4(5):6647 (2009), http://www.scholarpedia.org/article/Dyson_sphere

Some Dyson sphere surrogates

Stars are born and die in clouds of dust

← Protostars forming in Orion dust cloud (IRAS image)

AGB and Post AGB (old)

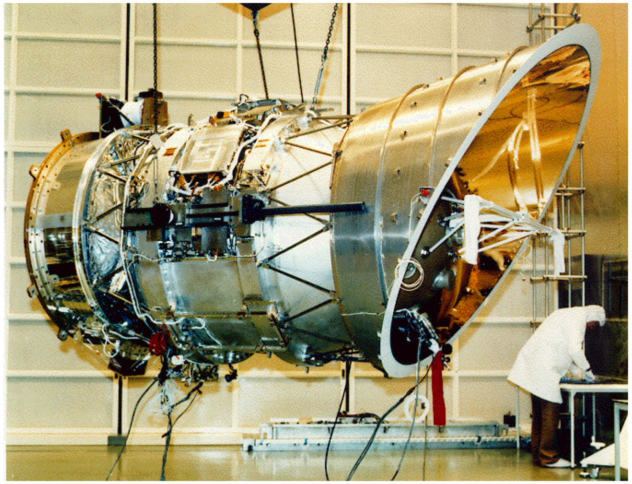
Mira (Omicron Ceti) in visible (Hubble image)

Miras variables, old, short-lived, circumstellar dust

Sum of many Planck spectra. Often have masers.

Also C stars

Dyson sphere IRAS search Carrigan, ApJ, 698, 2075 (2009)



Picture from From Infrared Processing and Analysis Center, Caltech/JPL. IPAC is NASA's Infrared Astrophysics Data Center.

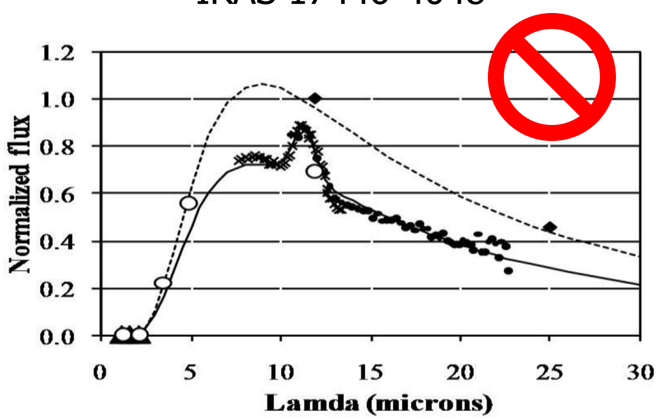
Low resolution spectrometer (LRS)

sensitivity: 2 Jy in 12 – 24 μm filters

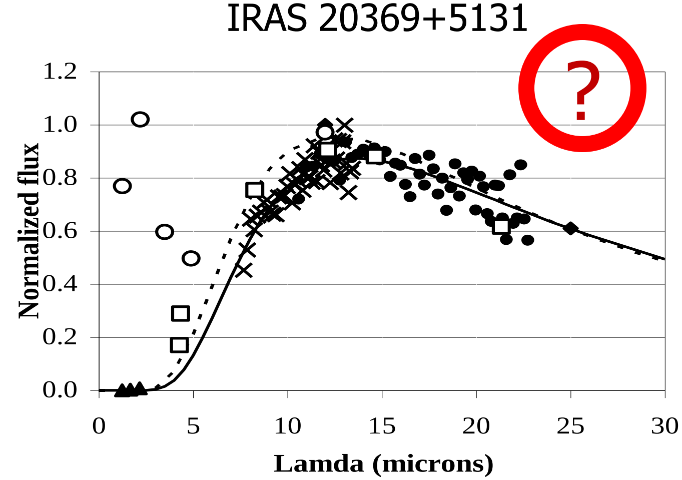
neat Calgary LRS database

11224 sources

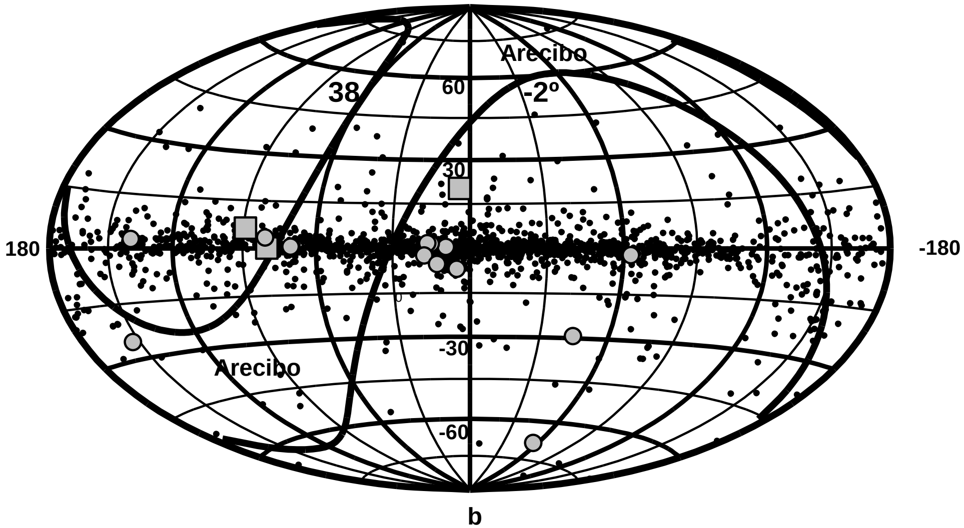
IRAS 17446-4048



IRAS 20369+5131



Dyson sphere summary



Results

3 faintly interesting, 13 poor

Planned SETI search with

Allen telescope on some

Reach

300 pc or ~ 1000 ly, not uniform on sky

but no galactic bulge

L_{Dy} ~ Dyson sphere lifetime

P_{Dy} ~ $4*10^{26}$ W (star)

M_{Dy} ~ 10^{24} kg (~Earth)

Astroengineering

(M. Beech, *Rejuvenating the Sun and Avoiding Other Global Catastrophes*, Springer – New York, 2008)

Martin Beech

Many **Main Sequence** stars become red giants when the core hydrogen is exhausted.

The star becomes cooler and redder as it burns the core hydrogen.

The surface expands, luminosity increases. **"We" will all suffer Bruno's fate!**

destroy life at earth's orbit. Challenge to astrophysicists "**What would you do, professor, when our raging sun is about to reach out and consume us?**"

Try to mix unused hydrogen in the outer envelope with the core.

$$L = L_{KR} \frac{\mu^{7.5}}{(1+X)} M^5$$

$$\boxed{\frac{dL}{L} = 5\frac{dM}{M}}$$

With astroengineering could useful stellar life be extended, say by controlling luminosity?

•mixing core with outer layers

•inducing stellar mass loss (60%!)

•changing pressure by adjusting rotation rate

•increasing opacity by introducing heavy elements

These are no easy astroengineering projects!

Blue stragglers

Blue straggler - hot, massive star on main sequence beyond the AGB turnoff
Beech: some blue straggler stars might be examples of this type of astroengineering [*Earth, Moon, and Planets, 49, 177 (1990*)]

Had been a mystery but *Shara, et al. [ApJ L489, L59 (1997)]*. showed they could arise in "intimate" stellar encounters between stars in crowded globular clusters. **Collisions bad for planets, life**.

Consider as a natural example of what a grand astroengineering project might be.

L_s ~ stellar lifetime
P_s ~ $4*10^{26}$ W (star)
M_s ~ 10^{30} kg (~star)

Galactic scale artifacts

Possible model – galaxy filled with Dyson spheres

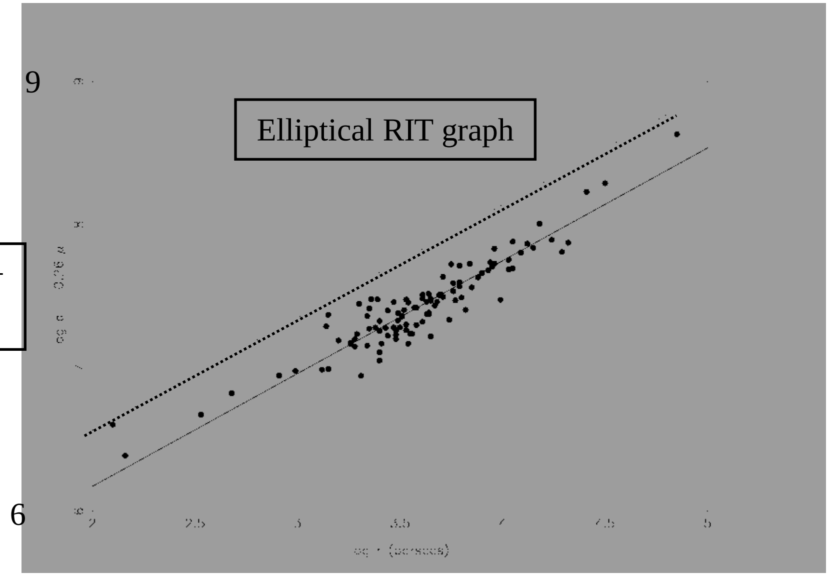
Actually just replication, slow interstellar travel

J. Annis, JBIS 52, 33 (99)

Outlier line is 1.5 magnitude or 75% in energy

No candidates in 137 galaxies

Jim Annis



L_g ~ stellar lifetime

P_g ~ 10^{37} W (stars in galaxy)

M_g ~ 10^{36} kg (10^{11} planets)

Natural dark galaxies and galaxy clusters?

VIRGOHI21 - CONTROVERSIAL

(astro-ph/0502312)

Example of a putative dark matter galaxy that could be an Annis outlier

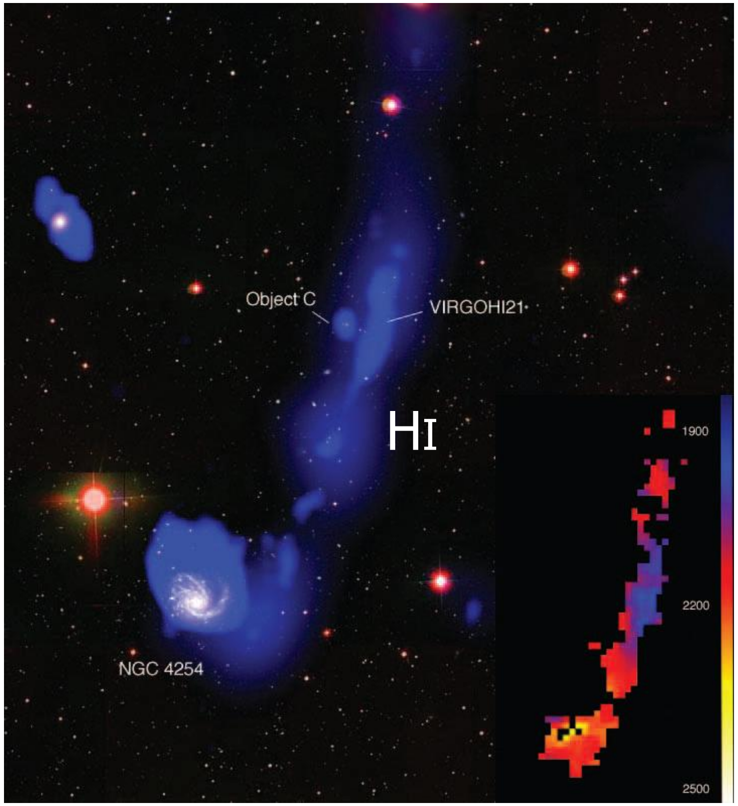
Is dark but probably not <u>our</u> dark matter (*SDSS image +Arecibo*)

Bullet cluster – some controversy

(*astro-ph/0309303v2*)

Red – gas (via xrays) slowed by EM interactions

Blue - dark matter via lensing (*NASA image*)



Fermi bubbles

Fermi paradox

slow interstellar travel possible (can cross galaxy as it rotates) so where are space aliens?

Voyager 1 is now traveling at solar escape velocity. For 100 times the energy, the velocity could have been raised to 400 km/s or 10^{-3}c. 60 my to cross galaxy.

Enrico Fermi

Whirlpool galaxy M51 30 mly

Image is Spitzer – IR red

Green – optical Hubble

Purple – xray – BH, NS

About 25% in relatively empty arms

< 5% unexplained voids or bubbles

IR does not follow voids

Fermi bubbles continued

Annis:

Try elliptical galaxies

Quotes for spirals

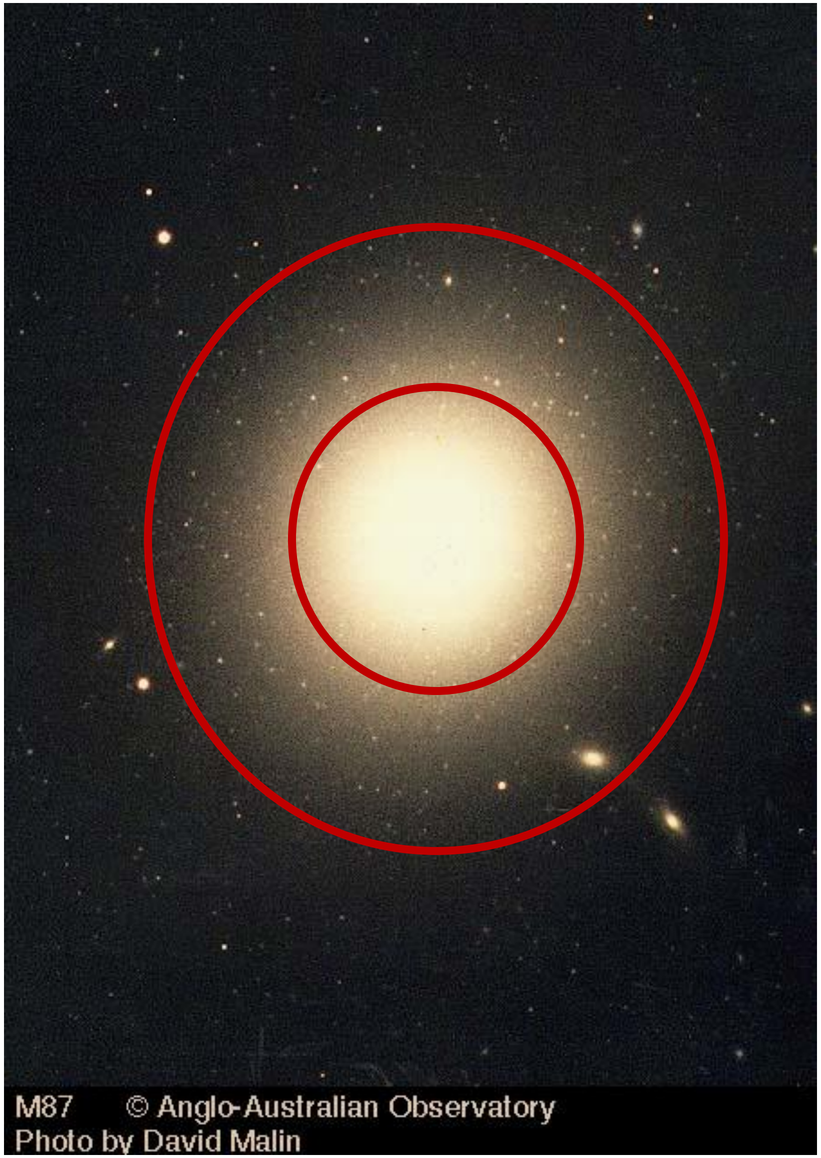
Dyson: "a type III in our own galaxy would change the appearance of the sky so drastically that it could hardly have escaped our attention,"

Annis: "It is quite clear that the Galaxy itself has not transformed into a type III civilization based on starlight, nor have M31 or M33, our two large neighbors."

Virgo A galaxy M87 55 mly

Anglo-Australian Observatory

Seems quite uniform



Beyond the galaxy –
is the Big Bang a Genesis message?

Vladimir Nikitin:

do physical and mathematic constants contain a message?

Dave Schramm - No

don’t use the Big Bang to support Genesis, religion

Brandon Carter - No

Anthropic conjecture,

cosmic landscape

Universe just right for us

Remember Bruno

don’t get burned at the stake

Vladimir Nikitin

Dave Schramm

Brandon Carter

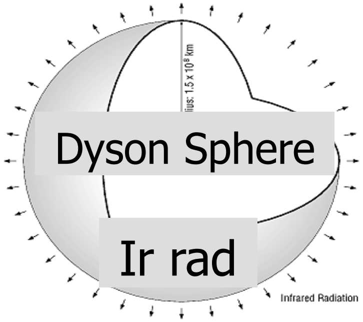
Summary table

	Examples of Interstellar Archaeology						
Kar. num.	Interstellar archaeology type	Reach (1000 ly)	L_c (lifetime)	L_c (kyrs)	Power Needs (W)	Mass Involved (kg)	Problems
0	SETI(radio)	to 0.25 now, 30 soon	civilization	5	10^6		often needs intent
0	planetary atmospheres	O(0.1)	atmospheric perturbation	O(0.1)		$\sim 10^{15}$	ambiguity
0	stellar salting	~30	λ isotope	$O(10^3)$		10^8	natural signals
0	nuclear waste	~30	λ waste	$O(10^1)$		10^8	ambiguity
I - II	spectral modulation	60 (also ext. gal.)	civilization	5	10^{26}	10^{24}/yr	natural signals
II	Dyson sphere	to 1	civilization dyn. stab.	5	$4*10^{26}$	10^{25}	mimics
II	stellar engineering	20	~stellar lives	10^6	$4*10^{26}$	10^{30}	~~blue stragglers~~
II.5 - III	Fermi bubble	$O(10^5)$	0.1 galaxy crossing	10^4	10^{35}	10^{34}	confusing signature
III	galactic Dyson sphere ensemble	$O(10^5)$	galaxy crossing	10^5	10^{37}	10^{36}	dark galaxies

Summary

Interstellar archaeology

- SETI cultural signals (**nearly possible**)
- Cultural planetary atmosphere signals (**look how fast we are screwing up our own**)
- Dyson sphere (tough)
- Astroengineering (really tough)
- Type III Kardashev ala Annis (mere replication of DS, a turn of a galaxy)



We are at the stage of Bruno and Galileo 400 years ago. The situation looks difficult but there are possibilities for progress.